TEXTURE PERCEPTION DETERMINED BY SOY PROTEIN ISOLATE AND INULIN ADDITION IN POTATO PUREE: LINKS WITH MECHANICAL AND MICROSTRUCTURAL FEATURES

MARÍA DOLORES ALVAREZ , MARÍA JOSÉ JIMÉNEZ , MARÍA DOLORES OLIVARES , LAURA BARRIOS and WENCESLAO CANET

ABSTRACT

This study evaluated the effect of adding soy protein isolate (SPI) and long-chain inulin (INL) blends with 10 different SPI : INL ratios on the textural, rheological and microstructural properties of freshly made and frozen/thawed potato puree. All the potato puree samples were subjected to a sensory texture profile analysis and a trained panel rated the intensity of six descriptors, while an untrained panel did the same on six selected frozen/thawed products. The main SPI : INL ratio effect remained significant for all the descriptors evaluated, when the analysis of variance was applied considering the untrained assessors as random effects. However, only trained panel scores for creaminess corresponded well with untrained assessor ratings. Rheological flow index values were linked with variations in perceived consistency, and geometric and surface textural attributes were explained by structural features such as the presence of INL crystallites and SPI coarse strands.

PRACTICAL APPLICATIONS

A potato puree (PP) serving of 200 g with added soy protein isolate (SPI) and/or inulin (INL) concentrations of 1.5–6% provides from 3 to12 g of SPI and/or INL, respectively. The presence of SPI strands is a dominant factor in texture perception of PP with regard to mouthfeel geometric attributes (visual graininess and fibrousness) and the after-feel attribute (mouth coating), while INL crystallites are the most important feature influencing creaminess. By adding small amounts of SPI (1.5%) together with INL at >3% increases the intensity of perceived creaminess, which was the most important descriptor in practical terms. In view of the foregoing, PP is a promising nutritious foodstuff for incorporating SPI and INL into the diet and even improving product texture.

INTRODUCTION

Food texture is defined as "all the rheological and structural (geometric and surface) attributes of the product perceptible by means of mechanical, tactile and, where appropriate, visual and auditory receptors" (Foegeding *et al.* 2011). Many instrumental methods are geared to determining rheological characteristics of food products (Wilkinson *et al.* 2000). Nevertheless, Heath and Lucas (1987) recognized that advances in understanding texture perception would depend on a multidisciplinary approach considering sensory research, physiology and research into food structure.

Basically, potato puree (PP) is formulated with native potato starch (Alvarez *et al.* 2009), and this starch-based food can be considered as a semisolid or soft-solid, viscoelastic material (Foegeding *et al.* 2011). Changing their composition by adding new ingredients would result in texture changes of the final product. Soy protein isolate (SPI) is an ingredient that can improve the organoleptic characteristics and nutritional value of food products (Tseng *et al.* 2009). Because of the health benefits of inulin (INL) in the human diet, much research has focused on this ingredient (Bot *et al.* 2004; González-Tomás *et al.* 2008).

The classification of textural terms for solids and semisolids gave rise to a profiling method of texture description (Texture Profile Analysis [TPA]) (Szczesniak 2002), providing qualitative and quantitative measures of a product's characteristics. Qualitative component comprises the descriptive terms, which define the sensory profile of the product, while quantitative component measures the intensity of each attribute perceived to be present (Carlucci and Monteleone 2001).

Starch-based products have been characterized by sensory descriptors such as mouth coating, creaminess or thickness (De Wijk *et al.* 2003, 2006). High-fat custards produced less sensation of dryness and fibrousness, and more sensations of flavor, creamy, fatty mouthfeel and after-feel than their zero fat-containing counterparts (De Wijk *et al.* 2003). Addition of olive oil enhanced the PPs sensory quality reducing granularity, denseness, cohesiveness, adhesiveness and fibrousness, and increasing homogeneity, ease of swallowing and palate coating (Alvarez *et al.* in press).

Two types of panels are used, namely the trained profile panel, commonly modeled after the General Foods Texture Profile Panel (Cardello *et al.* 1985) and the consumer panel, used frequently for obtaining hedonic texture measures. Research on starch-based foods is mostly conducted to study sensory characteristics rated by trained panels. However, no research has been conducted to assess the relationships between judgments of the perceived texture of starch-based foods by trained and untrained panelists. Moreover, in many research papers, a description of the model of analysis of variance (ANOVA) used is often ignored, even though there are two main ANOVA models (Næs and Langsrud 1998). Assessors should be considered as fixed parameters to analyze the type of individual differences, but as random variables to validate product differences (Carlucci and Monteleone 2001).

The first objective of this study was to evaluate the effect of the SPI : INL ratio and a freeze/thaw cycle on the perceived texture of PPs supplemented with different SPI/INL blends using a statistical approach to validate product differences as well as trained and untrained panel performances. A second objective was to study as to what extent the perceived texture in these systems is related to rheological flow properties and microstructural features.

MATERIALS AND METHODS

Materials

The potatoes used were tubers (cv Kennebec) from Aguilar de Campoo (Burgos, Spain). Readily dispersible SPI (PRO-FAM 646, ADM, Netherlands) was used without further purification. INL (Orafti HP, BENEO-Orafti, Tienen, Belgium) was a "long-chain" INL with a degree of polymerization, DP $\geq$ 23 and 99.5% purity (producer's data). κ-C (GENULACTA Carrageenan type LP-60) and XG (Keltrol F [E]) were donated by Premium Ingredients, S.L. (Girona, Spain). Eight SPI : INL ratio blends were added to samples: 1.5:4.5 (that is 1.5% of the total raw ingredients [SPI]/4.5% [INL]), 3:3, 4.5:1.5, 1.5:6, 3:4.5, 4.5:3, 6:1.5 and 6:6. Samples without added ingredients (0:0 control), with 6% added INL alone (0:6) and with 6% added SPI alone (6:0) were also prepared for both fresh PP (FPP) and those subjected to a freeze/thaw cycle (F/TPP).

Preparation of PP Samples

Tubers were manually washed, peeled and diced. PP were prepared in ~1,350-g batches from 790 g of potatoes, 300 mL of semi-skimmed in-bottle sterilized milk, 200 mL of water, 10 g of salt (NaCl) and 1.95 g each of two hydrocolloids, κ-C (Premium Ingredients, S.L.) and XG (Alvarez *et al.* 2009), using a TM 31 food processor (Vorwerk España, M.S.L., S.C., Madrid, Spain). The INL (0–6%) was previously dissolved in the 300 mL of milk and 150 mL of water at 70C for 15 min and stirred constantly with a magnetic stirrer. The ingredients were first cooked for 30 min at 90C (blade speed: 40 rpm) and any evaporated water was replaced gravimetrically. At this point, SPI which had previously been hydrated at a ratio of SPI to water of 1:5 was added at 1.5–6%. Water used to hydrate SPI was removed from the initial water content (200 mL). Next, all the ingredients were cooked at 90C for 5 min. The mash was ground for 40 s (1,200 rpm) and 20 s (2,600 rpm), and then homogenized through a stainless steel sieve (diameter 1.5 mm). Half of each fresh blend was analyzed immediately, and the other half was frozen and thawed. Freezing, thawing and heating procedures can be consulted (Alvarez *et al.* 2011; in press). Sample testing temperature was 55C as this is the preferred temperature for PP consumption.

Sensory Evaluation

PP samples which were subjected to sensory TPA, modified to evaluate vegetable purees according to UNE 87025 (1996) and other relevant international standards (ISO 2008), were used to select and define the descriptors included in the profile. Profile attributes were classified into four groups (Fernández *et al.* 2008; Alvarez *et al.* in press), but only six selected descriptors were rated in this study (Table 1). Descriptors are listed in order of perception according to ISO guidelines (ISO 2003). A panel of four assessors, previously trained (ISO 1993), evaluated the descriptors of the samples.

Daily, for 44 days at a fixed time (1:00 p.m.), assessors were given one PP sample (about 50 g each), for scoring the attributes of the 22 samples, in duplicate. All the samples were

TABLE 1. END TERMS AND DEFINITIONS OF THE DESCRIPTORS USED IN THE SENSORY EVALUATION OF POTATO PUREE

Descriptor	End terms	Definition
Visual graininess	Smooth-grainy	Geometrical textural attribute reflecting the size and shape of the particles
Creaminess	Not perceived-intense	Combined perception of fat, smoothness and thickness
Moisture	Dry-watery	Surface textural attribute reflecting the water content of the potato puree
Consistency	Thin-thick	Mechanical textural attribute relating to the force required to achieve a given deformation, penetration, or breakage of the potato puree
Fibrousness	Smooth-grainy	Geometrical textural attribute reflecting the graininess perceived during preparation of the sample in the mouth prior to swallowing
Mouth coating	Not perceived-intense	Property reflecting the sensation of potato puree remaining on the palate after swallowing or ingestion

served in white plastic vessels at a temperature of 55 ± 1C. For each sample, panelists evaluated the perceived intensity of the attributes on 8 cm descriptive linear scales labeled at each anchor (left anchor: 1 = "not detectable"; right anchor: 9 = "extremely intense").

An untrained panel of 27 assessors (eight males and 19 females) rated the intensity of the descriptors on only six selected F/TPP samples, in triplicate, over six sessions and each panelists evaluated three samples per session. These samples were selected in order to be sure that the variation between them was sufficiently large (considerable differences can be observed between the microstructure of these samples; see the Microstructure Examination subsection). At the start of each session, untrained panelists were given a printed response sheet with written instructions for the test, including the definition of each attribute to be judged during the session (Table 1), as well as the main adjectives corresponding to each anchor of the scale. In addition, untrained panelists were given a 20-min orientation session on the day before the test session; the panel leader explained the objectives of the study and untrained panelists were instructed to perform exactly the same sensory/psychophysics tasks than the trained panelists. These tasks included discussion in the rendering of operational definitions and scaling of each specific textural attribute. At each session, the untrained panelists were encouraged to refer to instructions and definitions of the attributes, and other spoken explanations were given to the panel when required. Moreover, each panelist was observed while he/she made the trial evaluations. The untrained panel had never previously evaluated PPs, although many had previously participated in making textural or other analytical sensory scores of a variety of foods. Definitely, the untrained panelist did not evidence difficulty to evaluate these descriptors in the six selected F/TPP samples. Similarly, samples were served at about 55 ± 1C in white plastic vessels, and the intensity of each attribute was scored as indicated above. Still mineral water was used as palate cleanser. The untrained panel was asked to score the overall acceptability (OA) of each sample based on texture, color and taste, on a 9-point hedonic scale (with 8 cm) labeled at each anchor (left anchor: 1 = "dislike extremely"; right anchor: 9 = "like extremely").

Rheological Measurements

A Bohlin CVR 50 controlled stress rheometer (Bohlin Instruments Ltd., Cirencester, UK) was used to conduct steady flow tests using a plate-plate sensor system with a 2-mm gap (PP40, 40 mm) and a solvent trap to minimize moisture loss during tests. After loading the sample, a waiting period of 5 min allowed the sample to recover and reach 55C with a Peltier Plate system (–40–+180C; Bohlin Instruments). In the flow test, shear stress was linearly increased until a shear rate of about 100/s was reached in about 5 min. Experimental data from ascending rheograms were fitted to the Ostwald de Waele model (Fernández *et al.* 2008), and consistency index (K, Pa·s^n) and flow behavior index (n) were obtained.

Apparent viscosity values at 50/s ($\eta_{app,50}$ [Pa·s]) would represent the approximate viscosity felt in the mouth (Bourne 2002). Thus, apparent viscosity values at 50/s were estimated (Eq. 1) and associated with oral evaluation of consistency.

$$\eta_{app,50} = K\dot{\gamma}^{n-1} \tag{1}$$

Kokini oral shear stress (σ_{oral} [Pa]) has been used as a physical index of the sensory perception of thickness (Bayarri *et al.* 2011). Therefore, n and K values were used to calculate the σ_{oral} and considered as an index of perceived thickness or consistency.

Scanning Electron Microscopy (SEM)

PP microstructure was examined by SEM using a Hitachi model S-2.100 microscope (Hitachi, Ltd., Tokyo, Japan). PP samples were air-dried, then mounted and sputter-coated with Au (200 A approx.) in a SPI diode sputtering system metallizer. Photomicrographs were taken with a digital system Scanvision 1.2 of Röntgenanalysen-Technik (800 × 1,200 pixel, Rontec, GmbH, Berlin, Germany).

Statistical Analysis

A three-way mixed-model ANOVA (SPI : INL ratio [S], treatment [T], i.e., performance or not of a freeze/thaw cycle and assessor [A]) with interactions was applied to the sensory descriptors evaluated by the trained panel, assuming that main effects and interactions were fixed effects. A two-way mixed-model ANOVA (SPI : INL ratio [S], treatment [T] and S × T) was also applied to the descriptors, likewise, ignoring random effects. Subsequently, a three-way mixed-model ANOVA was performed on the descriptors rated by the untrained panel to analyze the SPI : INL ratio, assessor (A) and replicate (R) effects and their interactions, again assuming that main effects and interactions were fixed effects. Next, a two-way mixed-model ANOVA (S, A and S × A) was applied, considering assessors and interaction as random effects (Carlucci and Monteleone 2001). Minimum significant differences were calculated using Fisher's least significant difference test (LSD; 95%).

In turn, a two-way mixed-model ANOVA (S, T and S × T) was applied to rheological data (n, K, $\eta_{app,50}$ and σ_{oral}). Significant differences were determined using Fisher's test (LSD, 99%). Correlations between descriptors rated by untrained and trained panels were determined by multiple regressions with confidence intervals of 95%. Pearson correlations were also established between rheological properties and perceived consistency rated by the trained panel. All analyses were performed using Statistical Package for the Social Sciences (SPSS) 19.0 software (SPSS, Inc., Chicago, IL).

RESULTS AND DISCUSSION

Sensory Properties Evaluated by the Trained Panel

The three-way mixed-model ANOVA showed a significant ($P < 0.05$) SPI : INL ratio and treatment main effects for all the descriptors (Table 2). Furthermore, S × T interactions were significant in all cases. Assessors were not significant for five descriptors, showing consistency between judges for these attributes. However, assessors were a significant source of variation in the case of fibrousness, indicating that additional training in the use of this descriptor could be needed. Even so, the effect of T × A and S × A interactions was not significant for all textural attributes, indicating a good level of agreement among the panel members regarding their evaluations. According to Carlucci and Monteleone (2001), as assessors were considered as fixed effects, no conclusions can be extended to the population from which the assessors were drawn.

Effect of the SPI : INL Ratio in the FPP and F/TPP Samples. After considering only S and T effects and their interaction, the two-way mixed-model ANOVA again showed that both main effects and interaction were a significant ($P < 0.05$) source of variation for all attributes (data not shown). Table 3 shows the mean values of each descriptor for both FPP and F/TPP samples. In the FPP samples, scores for graininess were very low and those for creaminess very high, for the control and all the samples with higher INL contents. However, by increasing SPI concentrations, perceived graininess increased and creaminess decreased. All the other FPP samples had significantly higher moisture and lower consistency scores when compared with the 0:0 control, indicating that either SPI or INL are hygroscopic ingredients and behaved as soft fillers. Exudation of the continuous liquid phase of gels during compression gives rise to watery/juicy sensory attributes (van Vliet *et al.* 2009), although the microstructural characteristics of the gels are also involved. Long-chain INL structure resembles that of a network of fat crystals in oil, as this type of INL forms small microcrystal aggregates that occlude a large amount of water, thereby creating a smooth and creamy texture (Bot *et al.* 2004; Guggisberg *et al.* 2009). Similarly, an important functional property in SPI is gelation during thermal treatment with desirable water-holding capacity (Tseng *et al.* 2009). However, FPP samples with an added 6:6 ratio had the lowest consistency score, suggesting that perceived water content is not the only factor influencing perceived consistency in FPP products.

Significantly, fresh 0:0 control and samples with added 0:6, 3:3 and 1.5:6 ratios had the lowest fibrousness scores, while

TABLE 2. MIXED ANALYSIS OF VARIANCE ON THE SENSORY ATTRIBUTES RATED BY THE TRAINED PANEL (11 SPI : INL RATIOS, FPP AND F/TPP SAMPLES, FOUR ASSESSORS). *F* AND *P* VALUES

	SPI : INL ratio (S) (df = 10)		Treatment (T) (df = 1)		Assessor (A) (df = 3)		S × T (df = 10)		T × A (df = 3)		S × A (df = 30)	
Descriptor	*F* value	*P* value	*F* value	*P* value	*F* value	*P* value	*F* value	*P* value	*F* value	*P* value	*F* value	*P* value
Visual graininess	104.89	0.000	254.86	0.000	0.47	0.708	57.64	0.000	1.44	0.284	1.48	0.252
Creaminess	27.03	0.000	9.05	0.006	1.03	0.414	3.39	0.020	0.13	0.938	1.08	0.504
Moisture	59.07	0.000	198.30	0.000	2.68	0.090	32.11	0.000	0.44	0.727	0.93	0.584
Consistency	51.24	0.000	837.29	0.000	2.77	0.093	11.72	0.000	0.90	0.472	0.54	0.908
Fibrousness	65.44	0.000	42.60	0.000	7.59	0.003	24.37	0.000	1.05	0.400	1.54	0.202
Mouth coating	42.99	0.000	97.50	0.000	0.71	0.569	4.92	0.002	3.45	0.057	1.51	0.246

F values calculated considering main effects and interactions as fixed parameters.

SPI, soy protein isolate; INL, inulin; FPP, fresh potato puree; F/TPP, potato puree subjected to a freeze/thaw cycle.

TABLE 3. MEAN VALUES OF DESCRIPTOR SCORES RATED BY THE TRAINED PANEL AND CORRESPONDING FISHER'S LEAST SIGNIFICANT DIFFERENCE FOR THE 22 FPP AND F/TPP SAMPLES

SPI : INL ratio	Treatment	Visual graininess	Creaminess	Moisture	Consistency	Fibrousness	Mouth coating
0:0	FPP	$1.55 \pm 0.26_{GH}$	$8.53 \pm 0.36*_{AB}$	$1.85 \pm 0.24_{F}$	$7.30 \pm 0.36*_{A}$	$1.27 \pm 0.09*_{H}$	$4.07 \pm 0.36*_{C}$
	F/TPP	$1.70 \pm 0.22_{e}$	$7.73 \pm 0.15_{c}$	$1.80 \pm 0.23_{e}$	$8.27 \pm 0.38_{a}$	$1.77 \pm 0.12_{ghij}$	$4.75 \pm 0.26_{cde}$
0:6	FPP	$1.57 \pm 0.30_{FGH}$	$8.80 \pm 0.11_{A}$	$6.32 \pm 0.22*_{A}$	$5.45 \pm 0.53*_{C}$	$1.42 \pm 0.25_{FGH}$	$2.80 \pm 0.22*_{D}$
	F/TPP	$1.30 \pm 0.18_{e}$	$8.88 \pm 0.13_{a}$	$4.80 \pm 0.36_{b}$	$6.75 \pm 0.24_{bcdefg}$	$1.30 \pm 0.08_{k}$	$4.40 \pm 0.37_{cde}$
1.5:4.5	FPP	$1.92 \pm 0.17_{DEF}$	$8.67 \pm 0.17_{A}$	$5.60 \pm 0.43*_{CD}$	$4.17 \pm 0.33*_{EFGH}$	$1.90 \pm 0.22*_{DE}$	$3.32 \pm 0.36*_{D}$
	F/TPP	$1.72 \pm 0.25_{e}$	$8.18 \pm 0.65_{abc}$	$4.82 \pm 0.31_{b}$	$6.25 \pm 0.53_{gh}$	$1.42 \pm 0.12_{ijk}$	$4.05 \pm 0.46_{def}$
3:3	FPP	$1.50 \pm 0.26_{H}$	$8.13 \pm 0.36*_{BC}$	$6.10 \pm 0.18*_{ABC}$	$4.57 \pm 0.31*_{DEF}$	$1.40 \pm 0.22_{GH}$	$3.15 \pm 0.31*_{D}$
	F/TPP	$1.40 \pm 0.18_{e}$	$8.65 \pm 0.19_{ab}$	$3.12 \pm 0.22_{d}$	$8.47 \pm 0.40_{a}$	$1.40 \pm 0.22_{jk}$	$5.12 \pm 0.58_{bc}$
4.5:1.5	FPP	$2.62 \pm 0.15*_{A}$	$7.30 \pm 0.55*_{DE}$	$6.15 \pm 0.46*_{AB}$	$3.52 \pm 0.41*_{IJ}$	$2.62 \pm 0.33_{A}$	$4.90 \pm 0.68*_{B}$
	F/TPP	$4.07 \pm 0.29_{c}$	$6.65 \pm 0.80_{de}$	$4.10 \pm 0.48_{c}$	$6.27 \pm 0.41_{fgh}$	$2.95 \pm 0.26_{cd}$	$5.85 \pm 0.84_{ab}$
6:0	FPP	$1.95 \pm 0.13*_{CDE}$	$6.78 \pm 0.31_{E}$	$5.97 \pm 0.58*_{ABCD}$	$3.87 \pm 0.46*_{GHIJ}$	$2.20 \pm 0.36_{BCD}$	$5.97 \pm 0.33_{A}$
	F/TPP	$2.82 \pm 0.38_{d}$	$6.58 \pm 0.50_{de}$	$4.20 \pm 0.29_{c}$	$5.85 \pm 0.24_{h}$	$2.30 \pm 0.45_{ef}$	$5.75 \pm 0.76_{ab}$
1.5:6	FPP	$1.60 \pm 0.24_{EFGH}$	$8.63 \pm 0.17_{AB}$	$4.62 \pm 0.26*_{E}$	$5.67 \pm 0.33*_{BC}$	$1.55 \pm 0.26_{EFGH}$	$3.07 \pm 0.99_{D}$
	F/TPP	$1.77 \pm 0.17_{e}$	$8.23 \pm 0.48_{abc}$	$5.52 \pm 0.41_{a}$	$8.52 \pm 0.46_{a}$	$1.55 \pm 0.17_{hijk}$	$3.42 \pm 0.42_{f}$
3:4.5	FPP	$2.10 \pm 0.22*_{BCD}$	$7.65 \pm 0.21_{CD}$	$5.75 \pm 0.35_{BCD}$	$3.85 \pm 0.13*_{HIJ}$	$2.17 \pm 0.22_{CD}$	$3.30 \pm 0.45*_{D}$
	F/TPP	$2.70 \pm 0.22_{d}$	$7.98 \pm 0.42_{bc}$	$4.00 \pm 0.41*_{c}$	$6.60 \pm 0.45_{cdefg}$	$2.15 \pm 0.21_{fg}$	$4.00 \pm 0.57_{ef}$
4.5:3	FPP	$2.25 \pm 0.26*_{BCD}$	$6.93 \pm 0.30_{E}$	$6.00 \pm 0.28_{ABCD}$	$4.17 \pm 0.31*_{FGH}$	$2.37 \pm 0.30_{ABC}$	$5.02 \pm 0.26*_{B}$
	F/TPP	$2.95 \pm 0.29_{d}$	$6.98 \pm 0.74_{d}$	$4.27 \pm 0.48_{c}$	$6.92 \pm 0.09_{bcd}$	$2.60 \pm 0.29_{de}$	$5.90 \pm 0.34_{a}$
6:1.5	FPP	$2.22 \pm 0.33*_{BCD}$	$7.23 \pm 0.51*_{DE}$	$5.52 \pm 0.38_{D}$	$3.47 \pm 0.29*_{J}$	$2.30 \pm 0.18*_{ABC}$	$5.20 \pm 0.35*_{B}$
	F/TPP	$5.12 \pm 0.55_{b}$	$6.60 \pm 0.47_{de}$	$5.35 \pm 0.41_{a}$	$6.52 \pm 0.45_{defg}$	$3.57 \pm 0.43_{b}$	$6.27 \pm 0.41_{a}$
6:6	FPP	$2.40 \pm 0.34*_{BC}$	$7.03 \pm 0.62*_{E}$	$5.97 \pm 0.25*_{ABCD}$	$2.77 \pm 0.22*_{K}$	$2.35 \pm 0.21*_{ABC}$	$4.90 \pm 0.41*_{B}$
	F/TPP	$6.92 \pm 0.74_{a}$	$5.98 \pm 0.41_{e}$	$5.15 \pm 0.26_{ab}$	$6.30 \pm 0.48_{efgh}$	$4.15 \pm 0.48_{a}$	$6.12 \pm 0.58_{a}$

Attributes evaluated on 8 cm descriptive linear scales labeled at each anchor: (left anchor: 1 = "not detectable"; right anchor: 9 = "extremely intense").
$_{A–K}$ for each descriptor and for the FPP samples mean values without the same letter are significantly different ($P < 0.05$).
$_{a–k}$ for each descriptor and for the F/TPP samples mean values without the same letter are significantly different ($P < 0.05$).
* For each descriptor and for the same SPI : INL ratio mean values between FPP sample and its F/TPP counterpart are significantly different ($P < 0.05$).
SPI, soy protein isolate; INL, inulin; FPP, fresh potato puree; F/TPP, potato puree subjected to a freeze/thaw cycle.

samples with higher SPI contents had the highest fibrousness ratings. Samples with higher SPI and INL contents also presented the highest and lowest scores, respectively, for mouth coating. Stading and Hermansson (1990) found that 10–12% solutions of β-lactoglobulin preheated to 90–95C formed fine-stranded gels with flexible or rigid strands at low and high pH, respectively. Surely, the presence of such SPI threads provoked an increase in intensity of fibrousness and mouth coating detected in the samples with higher SPI contents.

In turn, F/TPP samples with higher SPI contents were also more negatively affected by a freeze/thaw cycle and registered a significant increase in surface graininess as compared with their FPP counterparts (Table 3). Hashizume *et al.* (1971) reported that soybean proteins, when frozen in a solution, associate by intermolecular S–S bonds and become partly insoluble after thawing because they are closer to each other due to the more highly concentrated solution produced by the partially frozen water. It is thought that these changes might lead to a pronounced increase in visual graininess and a more significant decrease in creaminess in the frozen samples with higher SPI concentrations when compared with their FPP counterparts. Conversely, when higher amounts of INL were added to F/TPP samples, they had a significantly lower grainy appearance and higher creaminess scores than those with added SPI at the higher concentrations. This result is in accordance with that observed previously in low-fat and whole milk set yoghurt (Guggisberg *et al.* 2009). The authors reported that with rising INL concentration, perception of the creaminess increases as well. When F/TPP samples with a higher added INL content were thawed by microwave, the water accumulated in INL crystallites probably tended to diffuse uniformly within the matrix, giving rise to a homogeneous structure due to readsorption of the water by the amylose. It is hypothesized that the presence of INL reduces starch retrogradation and may be effective in the melting of retrograded starch during thawing.

Finally, the incorporation of both SPI and INL ingredients, either alone or blended, significantly decreased the perceived moisture in the F/TPP samples as compared with their FPP counterparts, except in the samples with an added 6:1.5 ratio, which was also accompanied by a significant rise in consistency. This was due to intracellular water being drawn out osmotically when the product was thawed because of the freezing-induced concentration of the cell mass (Fernández *et al.* 2008). As a consequence, the perceived fibrousness and mouth coating were also mostly higher in the F/TPP samples than in their FPP counterparts.

Sensory Properties Evaluated by the Untrained Panel

Main Effects and Interactions as Fixed Parameters. The three-way mixed-model ANOVA indicated a significant ($P < 0.05$) SPI : INL ratio and assessor main effects for all the descriptors and the OA (Table 4). In these cases, it is important to know whether assessor variability may influence the estimation of SPI : INL ratio differences. The significance or not, of the effect of S × A interaction can provide information on this point. The effect of this interaction was significant for all the descriptors, indicating a certain lack of concordance within the panel. A part of the S × A interaction is due to scale use, but the remaining part can be due to other individual differences such as sensitivity, motivation and culture (Carlucci and Monteleone 2001). In turn, replicate effects were also significant for all the descriptors, except for moisture, and the OA, confirming that members of an untrained panel give big variation in their analytical evaluations.

Assessors and Interaction as Random Effects. In spite of the relevance of the S × A interaction, the main SPI : INL ratio effect for all attributes and OA remained significant when the ANOVA model was applied considering assessor and interaction as random effects (Table 4). This means that when the influence of individual differences between assessors was eliminated, all textural attributes and OA differed among F/TPP samples. This result also indicates that the untrained panel did not create enough variance to obscure differences between samples with different added SPI : INL ratios. However, the S effect is much less significant for the model when assessor and interaction are considered as random variables, confirming that the distinction could have wide-ranging consequences (Næs and Langsrud 1998).

Effect of the SPI : INL Ratio in the F/TPP Samples. Once the mean values of the descriptors and the OA of samples and the significant differences between them (Table 5) had been established, the sensory differences were analyzed relating to SPI and INL content. Grainy appearance scores were higher for the control, for the samples with SPI added alone and unexpectedly for those with an added 1.5:6 ratio. Samples with added 0:6, 3:3 and 1.5:6 ratios registered the highest scores for creaminess. In turn, the moisture scores of samples with added INL alone and with a 4.5:3 ratio were significantly higher than that of the 0:0 control. The perceived consistency decreased significantly with the addition of INL alone but increased considerably with the addition of only SPI. Fibrousness of samples with added SPI alone did not differ appreciably from that of the 0:0 control, while mouth coating remained within very narrow margins of variation.

TABLE 4. MIXED ANALYSES OF VARIANCE ON THE SENSORY ATTRIBUTES RATED BY THE UNTRAINED PANEL (SIX SPI : INL RATIOS, 27 ASSESSORS, THREE REPLICATES). *F* AND *P* VALUES

	SPI : INL ratio (S)‡ (df = 5)		Assessor (A)‡ (df = 26)		Replicate (R)‡ (df = 2)		S × A‡ (df = 130)		A × R‡ (df = 52)		S × R‡ (df = 10)		SPI : INL ratio (S)† (df = 5)	
Descriptor	*F* value	*P* value	*F* value	*P* value	*F* value	*P* value	*F* value	*P* value	*F* value	*P* value	*F* value	*P* value	*F* value	*P* value
Visual graininess	623.71	0.000	958.30	0.000	46.22	0.000	171.28	0.000	1.38	0.231	3.28	0.001	15.31	0.000
Creaminess	104.98	0.000	435.85	0.000	20.59	0.000	147.17	0.000	1.15	0.386	1.13	0.343	8.71	0.000
Moisture	8.22	0.002	244.00	0.000	1.77	0.217	135.83	0.000	1.38	0.235	1.19	0.305	5.94	0.002
Consistency	503.37	0.000	415.76	0.000	31.77	0.000	88.59	0.000	1.09	0.442	0.90	0.529	34.17	0.000
Fibrousness	1,017.84	0.000	1,377.50	0.000	40.38	0.000	202.52	0.000	1.40	0.228	1.20	0.303	34.47	0.000
Mouth coating	71.57	0.000	366.74	0.000	23.95	0.000	119.01	0.000	1.19	0.351	1.98	0.038	4.88	0.000
OA	492.44	0.000	362.62	0.000	44.65	0.000	120.39	0.000	0.97	0.558	1.07	0.393	25.34	0.000

† *F* values recalculated considering S as fixed parameter and A effect and S × A interaction as random variables in the model.
‡ *F* values calculated considering main effects and interactions as fixed parameters.
SPI, soy protein isolate; INL, inulin; OA, overall acceptability.

TABLE 5. MEAN VALUES OF DESCRIPTOR AND OA SCORES RATED BY THE UNTRAINED PANEL AND CORRESPONDING FISHER'S LEAST SIGNIFICANT DIFFERENCE FOR THE SIX SELECTED F/TPP SAMPLES

SPI : INL ratio	Visual graininess	Creaminess	Moisture	Consistency	Fibrousness	Mouth coating	OA
0:0	$4.51 \pm 2.33_a$	$5.98 \pm 1.62_b$	$4.98 \pm 2.03_{bc}$	$5.29 \pm 2.00_b$	$5.38 \pm 2.24_a$	$5.47 \pm 1.92_{bc}$	$5.72 \pm 1.68_c$
0:6	$3.43 \pm 1.70_b$	$6.46 \pm 1.67_a$	$6.20 \pm 1.85_a$	$4.15 \pm 1.60_d$	$3.43 \pm 1.55_c$	$5.53 \pm 1.86_c$	$6.27 \pm 1.81_b$
3:3	$3.09 \pm 1.55_b$	$6.35 \pm 1.93_a$	$5.34 \pm 2.00_{bc}$	$4.67 \pm 2.02_c$	$4.49 \pm 2.43_b$	$5.69 \pm 1.98_{ab}$	$5.28 \pm 1.93_d$
6:0	$4.59 \pm 2.10_a$	$5.70 \pm 1.65_b$	$5.00 \pm 1.82_c$	$5.93 \pm 1.31_a$	$5.30 \pm 2.19_a$	$6.06 \pm 1.70_a$	$5.09 \pm 1.16_d$
1.5:6	$4.20 \pm 1.77_a$	$6.34 \pm 1.28_a$	$6.44 \pm 4.84_{ab}$	$4.67 \pm 1.51_c$	$3.58 \pm 1.62_c$	$6.02 \pm 1.67_{bc}$	$6.69 \pm 1.29_a$
4.5:3	$3.72 \pm 2.08_b$	$6.15 \pm 1.81_b$	$5.96 \pm 1.60_a$	$4.51 \pm 1.56_c$	$3.64 \pm 1.62_c$	$5.60 \pm 1.50_b$	$5.46 \pm 1.63_d$

Attributes evaluated on 8 cm descriptive linear scales labeled at each anchor: (left anchor: 1 = "not detectable"; right anchor: 9 = "extremely intense").
$_{abcd}$ for each descriptor and OA mean values without the same letter are significantly different ($P < 0.05$).
SPI, soy protein isolate; INL, inulin; OA, overall acceptability; F/TPP, potato puree subjected to a freeze/thaw cycle.

Note that although differences between samples were significant for the six attributes, scores in Table 5 show relatively little variation per attribute between samples, clearly indicating that the level of the training and the experience affected perception (Table 3). Additionally, samples with higher INL contents (0:6 and 1.5:6 ratios) had higher OA scores. In these samples, untrained panelists mainly associated OA with creaminess, smoothness, softness and pleasantness. De Wijk *et al.* (2003) stated that creaminess in custard desserts is related to a combination of sensations of mouthfeel (thickness and fattiness), after-feel (fatty coating and absence of fibrousness) and flavor/taste sensations (creamy and fatty flavors, an absence of bitterness). In contrast, presence of SPI at quite high concentrations (>1.5%) decreased the OA of the product compared with the control, mainly because assessors found that SPI gave the PPs an unfamiliar taste and odor.

Correlations Between Descriptors Rated by Untrained and Trained Panels

A graphical representation of the sensory profile for the six F/TPP samples rated by both trained and untrained panels is given in Fig. 1. In the samples rated by the trained panel (Fig. 1A), creaminess and consistency are the dominant descriptors in terms of the perceived intensity. Visual graininess and fibrousness were minimally perceived, while moisture and mouth coating were perceived to be moderately intense. In the samples rated by the untrained panel (Fig. 1B), all the descriptors were perceived as moderately intense. It is therefore clear that through experience, the trained assessors had developed a broader perceptual range of textures, which is in agreement with Cardello *et al.* (1985).

Mean scores for the trained panel were regressed against mean scores for the untrained panel for each descriptor. Correlation coefficients were not statistically significant for five of the six descriptors, indicating a lack of linearity between scores made by the two panels (data not shown). Creaminess was the only significantly correlated descriptor ($r = 0.88$). For this multimodal sensation, the slope of the regression equation was greater than 1.0 (2.84), confirming that a greater range of perceptual differences were perceived in the stimulus series by the trained panel (Cardello *et al.* 1985). Differences in the sensory scores assigned by trained and untrained assessors for the rest of the descriptors could be ascribed to: (1) those specific to PP, since the trained panel had been evaluating PP samples for 8 years; (2) those specific to the use of an 8 cm descriptive linear scale; or (3) simply due to differences between the techniques used by the trained and untrained assessors to evaluate these descriptors. Definitely, a common understanding of the meaning of different texture descriptors among the members of a sensory panel is needed to obtain reproducible results.

Rheological Behavior

Characterization of the PP Samples. Plots of shear stress versus shear rate for both FPP and F/TPP samples with added 0:0, 0:6, 3:3, 6:0, 1.5:6 and 4.5:3 ratios revealed a non-Newtonian flow behavior and exhibited typical pseudoplastic behavior and yield stress (Fig. 2A,B). The flow curves were similar in all the other products. This type of behavior is in accordance with that observed previously in PP (Fernández *et al.* 2008). Most of FPP and F/TPP samples with added SPI/INL blends presented lower resistance to flow than the controls, although the performance of a freeze/thaw cycle decreased the differences between the rheological behavior of the 0:0 control and that of the samples with added 3:3 and 1.5:6 ratios (Fig. 2B). F/TPP samples exhibited greater shear stress than their FPP counterparts.

Effect of the SPI : INL Ratio and a Freeze/Thaw Cycle on the Rheological Properties. The two-way mixed-model ANOVA indicated a significant ($P < 0.01$) S and T main effects for all the rheological properties and indices (Table 6). Furthermore, S × T interactions were significant for K, $\eta_{app,50}$ and σ_{oral} values. In spite of this, samples with

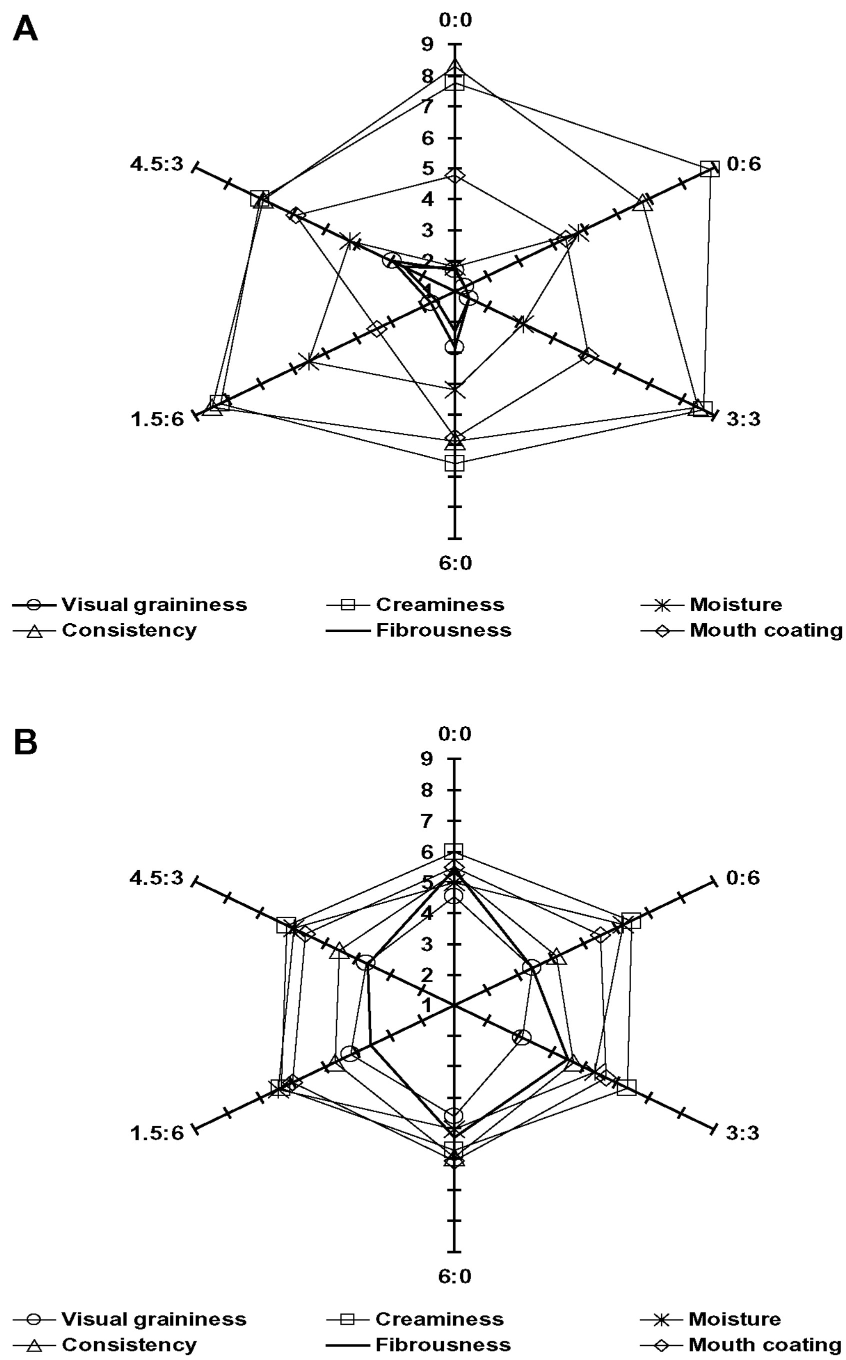

FIG. 1. COMPARISON OF RATINGS FOR DESCRIPTORS OF FROZEN/THAWED POTATO PUREE WITH ADDED SOY PROTEIN ISOLATE (SPI) AND INULIN BLENDS WITH SIX SELECTED SPI : I RATIOS
(A) Rated by the trained panel and (B) rated by the untrained panel.

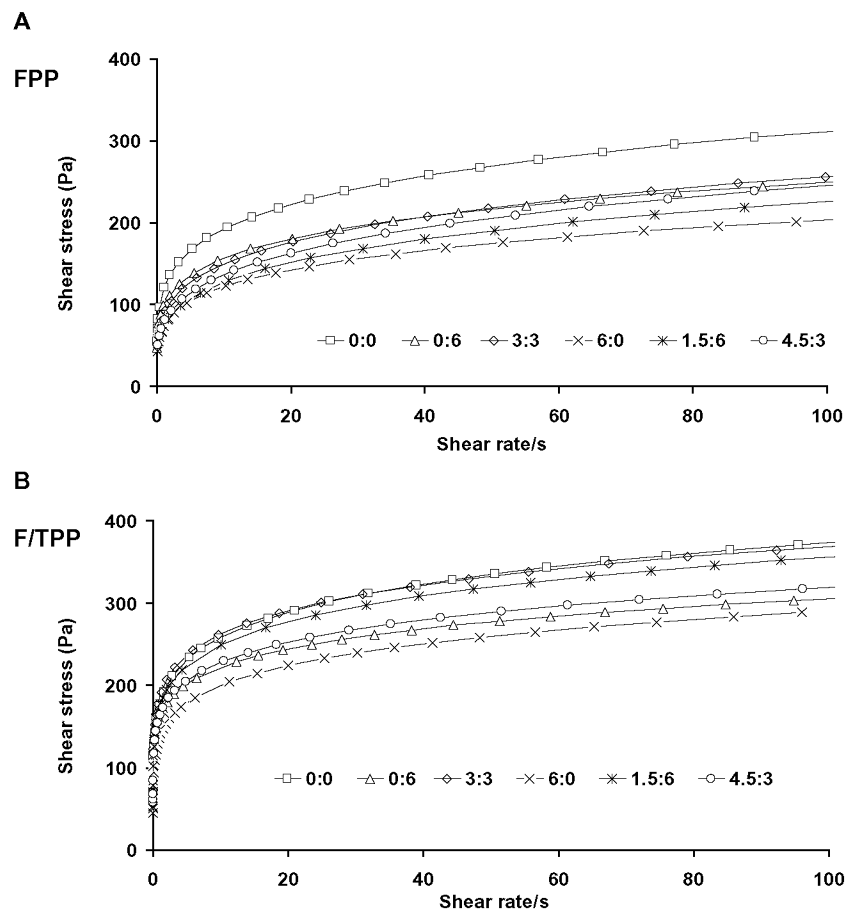

FIG. 2. STRESS SWEEP CURVES OF POTATO PUREE WITH ADDED SOY PROTEIN ISOLATE (SPI) AND INULIN (INL) BLENDS WITH SIX SELECTED SPI : INL RATIOS
(A) Fresh potato puree (FPP) and (B) frozen/thawed potato puree (F/TPP).

added SPI : INL ratios had similar pseudoplasticity (n) to the 0:0 control, although a freeze/thaw cycle increased pseudoplasticity of the samples.

Generally speaking, the addition of SPI/INL blends reduced the consistency index, the apparent viscosity at 50/s and the instrumental index of oral consistency with respect to the 0:0 control. At a fixed INL content, the K, $\eta_{app,50}$ and σ_{oral} values decreased with increasing SPI concentration from 1.5 to 6%, evidence of a decreased number of intermolecular cross-links resulting in a weaker matrix. This behavior is typical of gels filled with deformable particles (Jampen *et al.* 2001). According to the latter authors, in gels containing deformable particles, the linear decrease in storage modulus in line with increasing volume fractions is due to particle compliance under stress or to particle separation from the matrix, thereby causing gel weakening. At a fixed total concentration of 6%, the lowest K, $\eta_{app,50}$ and σ_{oral} values were recorded in the samples with added SPI alone (6:0 ratio). The K, $\eta_{app,50}$ and σ_{oral} values were significantly higher in the samples with only added INL than in those with added SPI alone, visibly indicating that the addition of INL alone caused rather less softening than adding SPI alone. As stated previously by Kaur and Gupta (2002), long-chain INL can form microcrystals. Thus, the smaller decrease observed in the rheological parameters of samples with an added 0:6 ratio could be attributed to the starch exclusion effect, which would lead to the formation of aggregates containing INL crystals. These aggregates would retain a high amount of liquid phase and the volume fraction would increase (Bot *et al.* 2004). This would justify that supplementary addition of INL exhibited a significant ($P < 0.01$) strengthening effect on the samples with added SPI alone.

Furthermore, it can be observed that in all cases, both consistency indices and apparent viscosity were significantly lower in the FPP samples than in the F/TPP ones due to an amylopectin retrogradation process. The appearance of a spongy, stratified and flaky texture as a result of freezing and thawing was also observed by Ferrero and Zaritzky (2000), but this study did not include sensory assessment of the samples. Mason (2009) stated that starch retrogradation causes syneresis and appearance changes such as graininess and opacity as well as texture changes, including loss of smoothness. In this study, XG (0.15% w/w) was added to PP samples in order to minimize amylose retrogradation, syner-

TABLE 6. EFFECTS OF SPI : I RATIO AND A FREEZE/THAW CYCLE ON FLOW RHEOLOGICAL PROPERTIES AND INDICES OF PP WITH ADDED SPI/INL BLENDS

Source	n	K (Pa·s^n)	$\eta_{app,50}$ (Pa·s)	σ_{oral} (Pa)
Main effects:				
SPI : INL ratio (S)				
0:0	0.19_{abcd}	146.25_{a}	6.24_{a}	224.62_{a}
0:6	0.17_{cd}	125.01_{bcd}	4.79_{c}	184.07_{cd}
1.5:4.5	0.22_{a}	108.28_{efg}	4.93_{bc}	177.74_{d}
3:3	0.19_{abcd}	134.26_{ab}	5.36_{b}	202.39_{b}
4.5:1.5	0.21_{ab}	121.68_{bcd}	5.32_{b}	192.67_{bc}
6:0	0.20_{abc}	100.13_{g}	4.18_{d}	157.63_{e}
1.5:6	0.19_{abcd}	125.15_{bcd}	4.93_{bc}	189.81_{bcd}
3:4.5	0.21_{ab}	121.08_{cde}	5.20_{bc}	191.05_{bcd}
4.5:3	0.21_{ab}	114.14_{def}	4.96_{bc}	179.38_{cd}
6:1.5	0.17_{d}	128.71_{bc}	4.78_{c}	183.73_{cd}
6:6	0.18_{bcd}	104.23_{fg}	3.87_{d}	156.89_{e}
P value	0.003	0.000	0.000	0.000
LSD (99%)	*0.03*	*12.93*	*0.51*	*13.68*
Freeze/thaw cycle (T)				
FPP	0.23_{a}	81.15_{b}	4.03_{b}	141.83_{b}
F/TPP	0.15_{b}	160.47_{a}	5.89_{a}	229.08_{a}
P value	0.000	0.000	0.000	0.000
LSD (99%)	*0.01*	*5.51*	*0.22*	*5.83*
Interaction				
S × T	0.103	0.000	0.001	0.000

$_{a–e}$ For each rheological property or index and effect studied mean values without the same letter are significantly different ($P < 0.01$).

SPI, soy protein isolate; INL, inulin; FPP, fresh potato puree; F/TPP, potato puree subjected to a freeze/thaw cycle; PP, potato puree; LSD, least significant difference.

esis and rheological changes after freezing (Alvarez *et al.* 2009), but as already stated XG addition does not prevent ice recrystallization nor amylopectin retrogradation.

High bilateral correlations of 0.92 and 0.97 were found between the $\eta_{app,50}$ and K and between the $\eta_{app,50}$ and σ_{oral}, respectively (Table 7), so only S × T interactions for K and σ_{oral} are shown in Fig. 3. The most remarkable effect was that the F/TPP samples with an added 3:3 ratio had notably higher K values than the 0:0 control (Fig. 3A), although there were no significant differences in the σ_{oral} values of the F/TPP samples with added 0:0 and 3:3 ratios (Fig. 3B).

TABLE 7. PEARSON CORRELATION COEFFICIENTS BETWEEN RHEOLOGICAL PROPERTIES, INDICES AND ORAL CONSISTENCY RATED BY THE TRAINED PANEL FOR PP SAMPLES WITH ADDED SPI/INL BLENDS

	n	K	$\eta_{app,50}$	σ_{oral}	Oral consistency
n	1	−0.90	−0.69	−0.82	−0.75
K	–	1	0.92	0.98	0.88
$\eta_{app,50}$	–	–	1	0.97	0.85
σ_{oral}	–	–	–	1	0.89
Oral consistency	–	–	–	–	1

SPI, soy protein isolate; INL, inulin; PP, potato puree.

Therefore, the presence of both ingredients at certain ratios was found to enhance the consistency of F/TPP samples when compared with those with either SPI or INL added alone. Tseng *et al.* (2009) reported that the addition of 5% (w/v) long-chain INL enhanced the gelation of SPI and the 7S (β-conglycinin)/11S (glycinin) mixture, which was evident from the increases in gel storage modulus by up to 13.6 and 10.1%, respectively.

Correlations ranging from −0.75 to 0.89 were found between the oral consistency perceived by the trained panel and the rheological properties and derived indices (Table 7). Therefore, differences in the rheological behavior of samples explain quite well the above sensory variations perceived with respect to sensory consistency. However, the other five sensory texture attributes cannot be related to a single physical property of the PP in a simple way.

Microstructure Examination

Figure 4 shows the morphological differences between the six selected F/TPP samples rated by both trained and untrained panels. The 0:0 control (Fig. 4A) consists mainly of a continuous phase (amylose/amylopectin matrix) due to the disruption and complete solubilization of the starch granules caused by cooking. It is clear that in the 0:6 ratio (Fig. 4B), INL crystallites were dispersed throughout the amylose/amylopectin matrix, forming a strong gel with characteristics of a one-phase system. Using optical microscopy, Zimeri and Kokini (2003) observed INL crystals immersed in the continuous phase in samples with 5% long-chain INL. Analogously, Bayarri *et al.* (2011), by means of SEM, observed the presence of INL aggregates embedded in the continuous matrix of starch–dairy systems. Even in this study, the probable loss of water due to a freeze/thaw cycle provoked the formation of closely packed INL crystallites in the INL-rich phase. This structure is associated with a significant increase in creaminess and moisture scores rated by both panels, and characterized by either lower sensory or instrumental consistencies in comparison with the F/TPP 0:0 control (Tables 3 and 5; Fig. 3). A clear relationship was observed between the microstructure of whey protein isolate/gellan gum gels, serum release and the grading of the sensory watery characteristic (van Vliet *et al.* 2009). The slight thinness found in 0:6 ratio should not be considered of major importance as the quality of the product was improved. Note that the untrained panel preferred the PPs enriched with the highest INL concentration used, this smoothness and decreased sensation of graininess being ascribed to increased INL. The decreased oral graininess is the result of the lubricating and coating properties of INL crystals, which clearly masked the fibrousness detected in the 0:0 control.

In the case of samples with an added 3:3 ratio (Fig. 4C), it is not possible to appreciate any gel SPI structure (probably

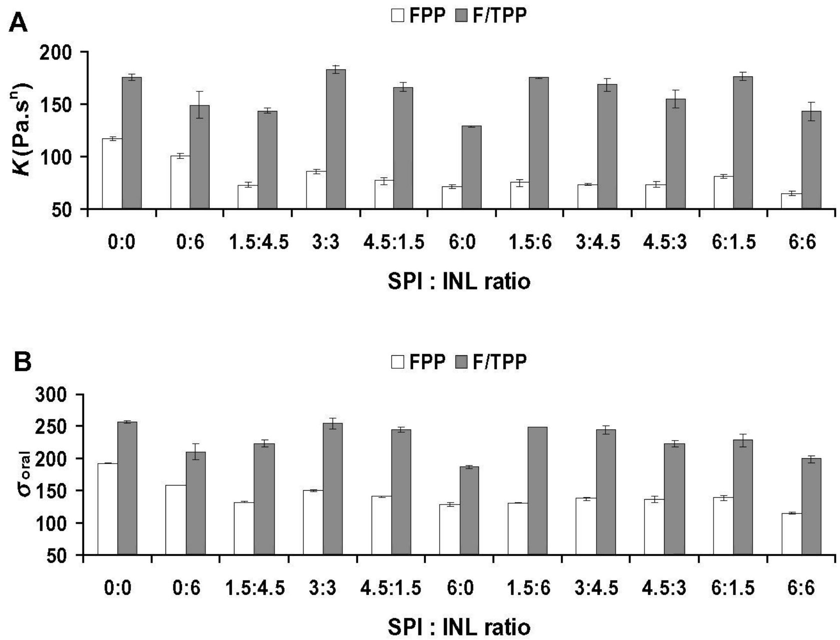

FIG. 3. RHEOLOGICAL BEHAVIOR OF FPP AND F/TPP WITH ADDED SPI AND INL BLENDS WITH ELEVEN DIFFERENT SPI : INL RATIOS
(A) Consistency index (K) and (B) Kokini oral shear stress (σ_{oral}). FPP, fresh potato puree; F/TPP, frozen/thawed potato puree; SPI, soy protein isolate; INL, inulin.

because no gelation occurred). In addition, the INL did not form a continuous phase, as its lower concentration reduced the density of these particles in the product. It is possible to appreciate spherical and obloid-shaped INL crystallites throughout the sample but with fewer interconnections between them compared with the added 0:6 ratio (Fig. 4B). This fact might have led to reduced lubrication and a drier sensation, as reflected by an increase in both the consistency index (Fig. 3A) and the perceived consistency accompanied by a decrease in the wet feeling in the mouth (Table 3).

On adding SPI alone at 6%, proteins formed a network composed predominantly of filamentous SPI aggregates (Fig. 4D), although some particulate clusters of aggregates can also be seen. For globular proteins, generally two different types of gel networks can be distinguished, fine-stranded and coarse networks, but intermediate structures have also been reported (Lakemond *et al.* 2003). This coarse-stranded SPI gel was characterized by a significant decrease in the rheological properties and consistency perceived by the trained panel. The influence of particle–matrix interactions was studied by van Vliet (1988), who found that a linear decrease in gel strength with an increase in volume fraction only occurred with noninteracting gel materials. As stress is applied to the system, small amounts of water may be released from the SPI strands; thus, forming an aqueous boundary layer around them and reducing any interactions with the amylose/amylopectin matrix. Addition of SPI alone gave rise to a less creamy, rougher product with more mouth coating, which could also be explained by the presence of these filamentous SPI aggregates.

The appearance of samples with an added 1.5:6 ratio (Fig. 4E) was quite similar to that of samples with added INL alone (Fig. 4B), forming a continuous INL network without appreciable protein inclusions. In contrast, the appearance of samples with an added 4.5:3 ratio was quite unlike that of samples with an added ratio of 3:3. In samples with 4.5% added SPI and 3% added INL (Fig. 4F), SPI again formed a filamentous network without distinguishable INL crystals, which would be preferentially excluded from the protein surfaces. Thus, SPI at 4.5% supports the INL structure by building up a second coarse-stranded network. There were also some differences between samples with added 6:0 and 4.5:3 ratios. When 4.5% SPI was blended with 3% INL (Fig. 4F), the SPI gel structure had thicker, more shrunken strands than with added SPI alone (Fig. 4D). In spite of staying hidden, INL crystallites significantly strengthened the F/TPP samples with SPI gel alone (Fig. 3). The presence of INL must have a synergistic effect on SPI gelation, and this effect may depend on SPI concentration, the SPI : INL ratio, and possibly solvent properties (e.g., water activity [A_w]). It is well known that freezing reduces A_w due to ice formation and the high concentrations of solutes in unfrozen water. When the concentration of SPI, was high, the addition of INL probably caused more A_w reduction, exerted stronger hydrogen bonding with water and/or produced greater physical interactions (e.g., entanglements) with SPI molecules. Such reactions, combined with the excluded volume effect, would lead to enhanced protein–protein interactions as manifested by the increase in rheological properties. According to Tseng *et al.*

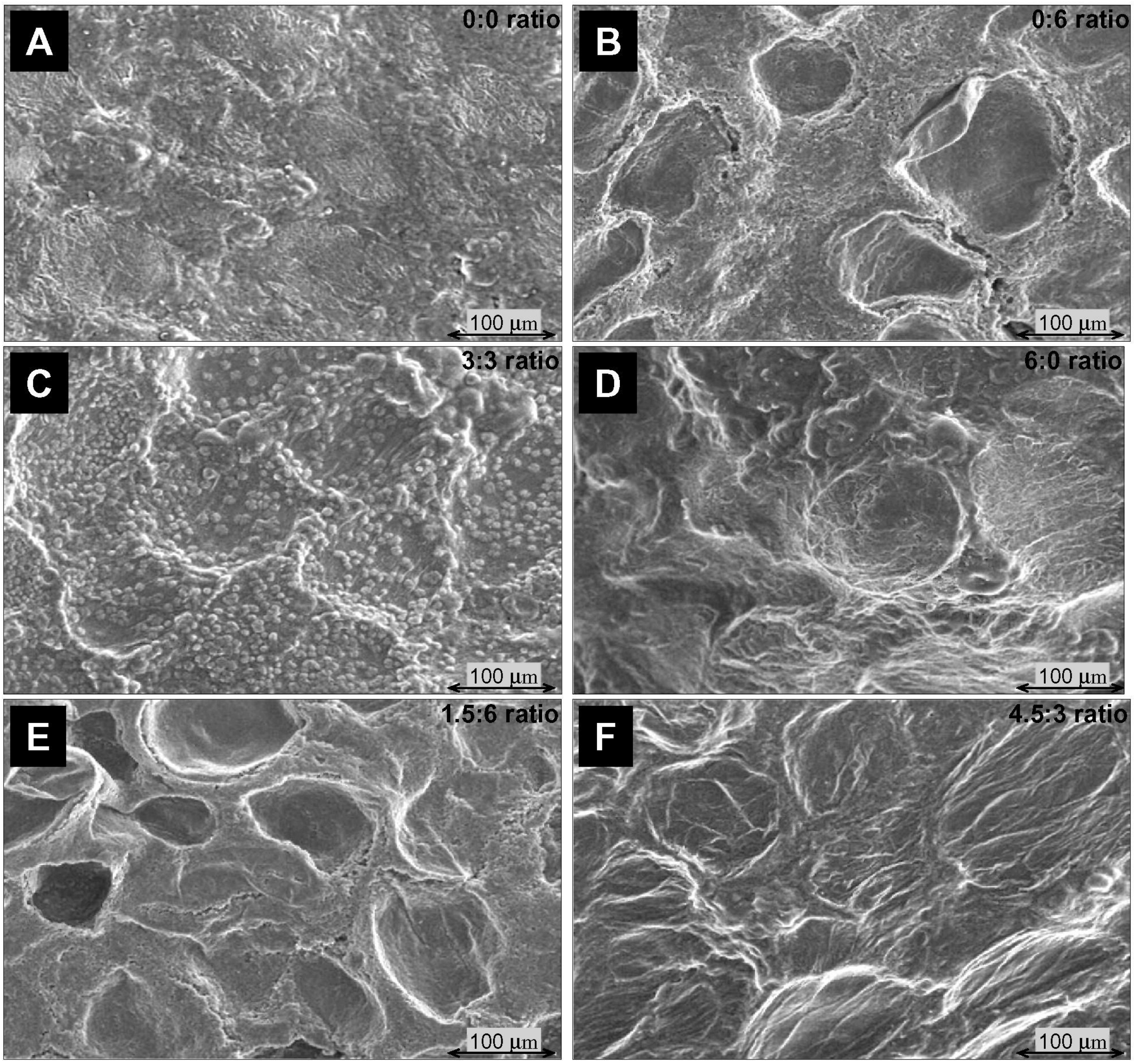

FIG. 4. MICROGRAPHS OF FROZEN/THAWED POTATO PUREE WITH ADDED SOY PROTEIN ISOLATE (SPI) AND INULIN (INL) BLENDS WITH SIX SELECTED SPI : INL RATIOS
(A) 0:0 ratio. (B) 0:6 ratio. (C) 3:3 ratio. (D) 6:0 ratio. (E) 1.5:6 ratio. (F) 4.5:3 ratio. Magnification was 200 (bar = 100 μm).

(2009), the excluded volume effect is likely the major force driving soy globulins into a more stable state in the presence of this neutral carbohydrate.

CONCLUSION

Despite an untrained panel being able to distinguish between PP samples with different added SPI : INL ratios, only a good linear correlation was observed between trained and untrained evaluations for creaminess. Perceived consistency rated by the trained panel was linked to flow rheological indices, which show that there is no interaction between the amylose/amylopectin matrix and the dispersed particles. Presence of SPI strands was a dominant factor in texture perception, regarding mouthfeel geometric attributes (visual graininess and fibrousness) and after-feel attribute (mouth coating), while INL crystallites were the main feature influencing creaminess. The addition of small amounts of SPI (1.5%) and INL at >3% increased the intensity of perceived creaminess. SPI–water interactions would appear to be weaker than those between INL and water, and the more fluid-like behavior observed in samples with added SPI at concentrations $\geq$ 4.5% may be attributable to water release from the SPI gel in the discontinuous phase. Microstructural characteristics are evidently needed to understand the non-mechanical part of the perceived texture in PPs with these added functional ingredients.

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